To select the best digital modulation, it is recommended that experimental effort begin as soon as possible. Since successful widespread implementation of digital video transmission will not occur for about two years or more, reasonable lead time is available.

Successful digital video transmission obviously requires inexpensive video decompression hardware. There is a high probability that the terrestrial HDTV standard (to be decided by the FCC in 1 1/2 to 2 years) will be modified for standard definition TV transmission by the developers for use on satellite and cable channels. At least one of the HDTV proponents already has such a unified approach, using the same receiver hardware for all the three applications. Since this will be a part of future TV receivers, Hye Crest will need to provide only transmission hardware, along with conditional access features. The video decompression will be a part of the TV receiver. At this point in time this is an optimistic prediction, but is only one of several possible scenarios. For example, there is no guarantee that the satellite and cable transmission standard will necessarily be like that of the terrestrial standard, although it would be advantageous to consumers to have such a unified standard. In any event, this hardware, if it proves to be economically feasible, could improve both the cable, fiber optic, and MLDS systems.

9. Other Modulation Methods

a) Spread spectrum systems. These are useful when a strong interference can be expected from an external source, which is not true here. Consequently, no advantage can be expected from such a modulation, especially for broadcast services. Further, a high speed (e.g., 5 Mbps data rate spread over 800 MHz) spread spectrum receiver is complex to implement. In addition, as in any data link, one needs video compression and decompression hardware, which is expensive and not readily available.

b) Digital FM and variations. A method of transmitting data as the baseband of FM, and using discriminator detection was described earlier. Slightly higher efficiency (lower transmitted power, smaller bandwidth, or, lower bit error rate) can be obtained in other forms of FM data modulation. Coherent detection, which is substantially more complicated than discriminator detection, leads to the increased efficiency, but is expensive to implement. This is not recommended for the Suite 12 system..

c) Amplitude Modulation (AM). The use of AM for video distribution may seem attractive because each channel requires only 6 MHz of bandwidth and a FM demodulator is not required. But an analysis of the system indicates serious disadvantages and unsurmountable problems. The transmitter power requirements at 28 GHz, for the required cell diameters, are far beyond the state-of-the-art. This is a result of the more stringent CNR and linearity requirements.

Repeaters, required for shadow area coverage, for AM systems cannot be used for the same reasons. Two-way communications cannot be used because of technical limitations on dynamic range requirements, the required subscriber transmitter power, and insufficient isolation.

It was shown earlier that FM transmission can give acceptable signal transmission range even with relatively low transmitter powers. The primary reason is that the (rain faded) CNR required for FM is low (13 dB in 20 MHz). The corresponding carrier-to-noise density ratio, C/No, is 86 dB-Hz. For AM the rain faded SNR(TASO) should be 42 dB. The corresponding C/No for AM is 109.8 dB-Hz. Hence an AM transmitter requires 23.8 dB more power per carrier. In Tables I-5.3 to I-5.7, the transmitter output power for a single FM carrier is 0.4W. For AM transmission this needs to be increased to 96W of output power for a single carrier, assuming that all other parameters (antenna gains) are unchanged.

When more than one channel is transmitted, the cases for AM becomes even worse. Considering the same system parameters, but now transmitting 49 channels of FM, the TWTA used for the transmitter must have a power rating of 98 watts. This can be calculated by multiplying the output power for each channel (-4 dBW - 0.4 W) by 49 and increasing the transmitter power by the required multichannel backoff for FM (7 dB).

The power rating for a TWTA used in an AM system can be calculated in a similar manner. In this case the required backoff is 15 to 20 dB (15 dB is used). The required TWTA power is 148.7 Kilowatts which is completely unrealistic. In the AM case, even if a single channel is transmitted, 15 to 20 dB backoff is required. This is due to the fact that intermodulation distortion products generated by the picture, color, and sound carriers must be 50 dB below the picture carrier level at the peak of sync. This means that the power rating for a TWTA transmitting a single channel of AM must be 3 Kilowatts.

If the same transmitting tube is used for FM or AM, the transmitting range for AM is greatly reduced. A TWTA rated at 96 watts used in a 49 channel system will have a clear weather cell radius of only 0.7 miles for AM. With FM this range is extended by a factor of 22 or 15 miles.

With AM transmission, repeaters cannot be implemented economically. Wideband repeater amplifiers, that can amplify all of the AM signals, will either introduce too much intermodulation noise, or will be required to be operated at a very high backoff, and consequently must have several Kilowatts of power rating. Filtering each channel and employing one amplifier per channel is not feasible since it would require filter Q's which are unattainable. The implication is that coverage for shadow areas will be impossible. In the FM based transmission this is unnecessary, since the central nodes of all the cells, except one master station, can simply act as high quality repeaters consisting of block conversion and amplification. Low level solid state repeaters are available for FM shadow area reception.

Since AM signals are extremely intolerant to interference, the (C/I values range from 45 to 55 dB), the spectral ban occupied by the AM signals cannot be used for any point-to-point or two-way links within a cell.

Return transmissions from the subscriber transmitter also require much higher power levels for AM then FM. Technologically this represents several problems: higher costs for subscriber transmitters and interference. Interference occurs between near by subscribers because the isolation requirements are much more stringent for AM then for FM (C/I of 15 dB for FM, C/I of 55 dB for AM). In addition, the dynamic range requirements, located at the node, of the receiver which is picking up the transmission from the subscribers represents a formidable technological problem. It must be capable of detecting very low level signals at the same location in which Kilowatt level signals are being broadcast.

Of all the modulation candidates studied, 20 MHz FM is the recommended candidate for very high quality TV multichannel distribution. It allows the combined use of polarization, frequency diversity, spacial diversity to optimize the use of the 1000 MHz frequency spectrum. It provides the simultaneous capability of TV distribution and two-way communications.

10. Interference Between Video Distribution and Point-to-Point Services

Suite 12 point-to-point terrestrial links can co-exist with Suite 12 video signals provided certain conditions are met. The line-of-sight of a point-to-point link should not go through the Suite 12 video central transmitter location. The point-to-point link receiver and transmitter dish diameter should be as large as possible, so that the its beamwidth is small and will offer even further reduction of interference signals from the Suite 12 video central transmitter.

We will first consider interference from the Suite 12 video system into a point-to-point link. The goal here is to give an example that a properly designed point-to-point link can co-exist with the Suite 12 video system and may be used as a backbone network for Suite 12.

Consider the Suite 12 video omni directional transmitter and a point-to-point link, shown in Figure II-10.1. Let "C" be the Suite 12 video transmitter location with a G_t = 10 dB omni directional antenna gain, P_t = 100 W transmitting amplifier, operating with 7 dB of output backoff (OBO), and F2 = 1 dB of feed loss. Let "B" be the transmitting system of the Suite 12 point-to-point link, and "A" be the receive side of this point-to-point link. This receiver has a noise figure of NF = 6 dB, for reception of a signal over bandwidth B (MHz). The minimum CNR of this link is denoted by CNRMIN, and is taken to be 10 dB. Then the wanted signal carrier power at "A" is

$$C = \text{CNRMIN} + [-228.6 + 10 \log B + 60 + 10 \log(300(10^{0.1NF} - 1))]$$

where the quantity in the square parentheses is the received noise power. The unwanted signal power in bandwidth B is given by

$$I = P_t(\text{dBW}) - \text{OBO} - \text{FL} + G_t - L + 10 \log(B/B_t) - \text{XPOL} + G_r(\theta)$$

where

B_t	is the bandwidth of the emitted signal at "C", in MHz (1000 MHz)
XPOL	is the cross-polarization advantage
G_r	is the on-axis gain of the receiver antenna at "A", in direction of "B", in dB
$G_r(\theta)$	is the off-axis gain of the antenna at "A" in the direction of the Hye Crest antenna "C"

From these quantities C/I can be computed. If it is assumed that at receiver "A" the interference level should be 3 or more dB lower than the noise level, the relation between the link parameters can be obtained by setting $N/I \geq 3$ dB. For the assumed parameters here this is equivalent to

$$20 \log D + XPOL - G_r(\theta) \geq 8.56, \text{ dB}$$

In the point-to-point link the receiving antenna need not be small, since it is not a consumer distribution system. We can assume a 15" receiver antenna, which has:

G_r = 38 dB

$G_r(5\text{ deg})$ = 14 dB

$G_r(10\text{ deg})$ = 9 dB

The off-axis gain is 1 to 3 dB more pessimistic than the rule-of-thumb values of $31 - 25 \log \theta$. Assuming that in clear weather an XPOL value of 25 dB is achievable, we arrive at

$$20 \log D \geq -2.44 \text{ for } 5^\circ \text{ separation}$$

or

$$D \geq 0.75 \text{ miles}$$

If XPOL is only 20 dB, D should be at least 1.34 miles, with 5° separation. These values can be improved if the point-to-point link has FM video. Such a link can be frequency offset from the Hye Crest FM carriers by 1/2 carrier separation. For such a separation we can assume an offset advantage of at least 20 dB. Hence D is 0.075 mile (400 ft), or 0.13 mile (709 feet) depending upon the XPOL of 25 or 20 dB respectively.

Consider next interference from the point-to-point link into the Hye Crest system. Since the Hye Crest is a broadcasting system, a large number of receivers will be located within the coverage area. The area of the coverage region that cannot be used for Hye Crest receivers is no more than a small fraction of the total area. With a pessimistic degree of approximation this is far less than 1%. Such areas can be covered for the Hye Crest customers with a passive repeater located such that the receiver antennas can be directed completely away from the interfering source.

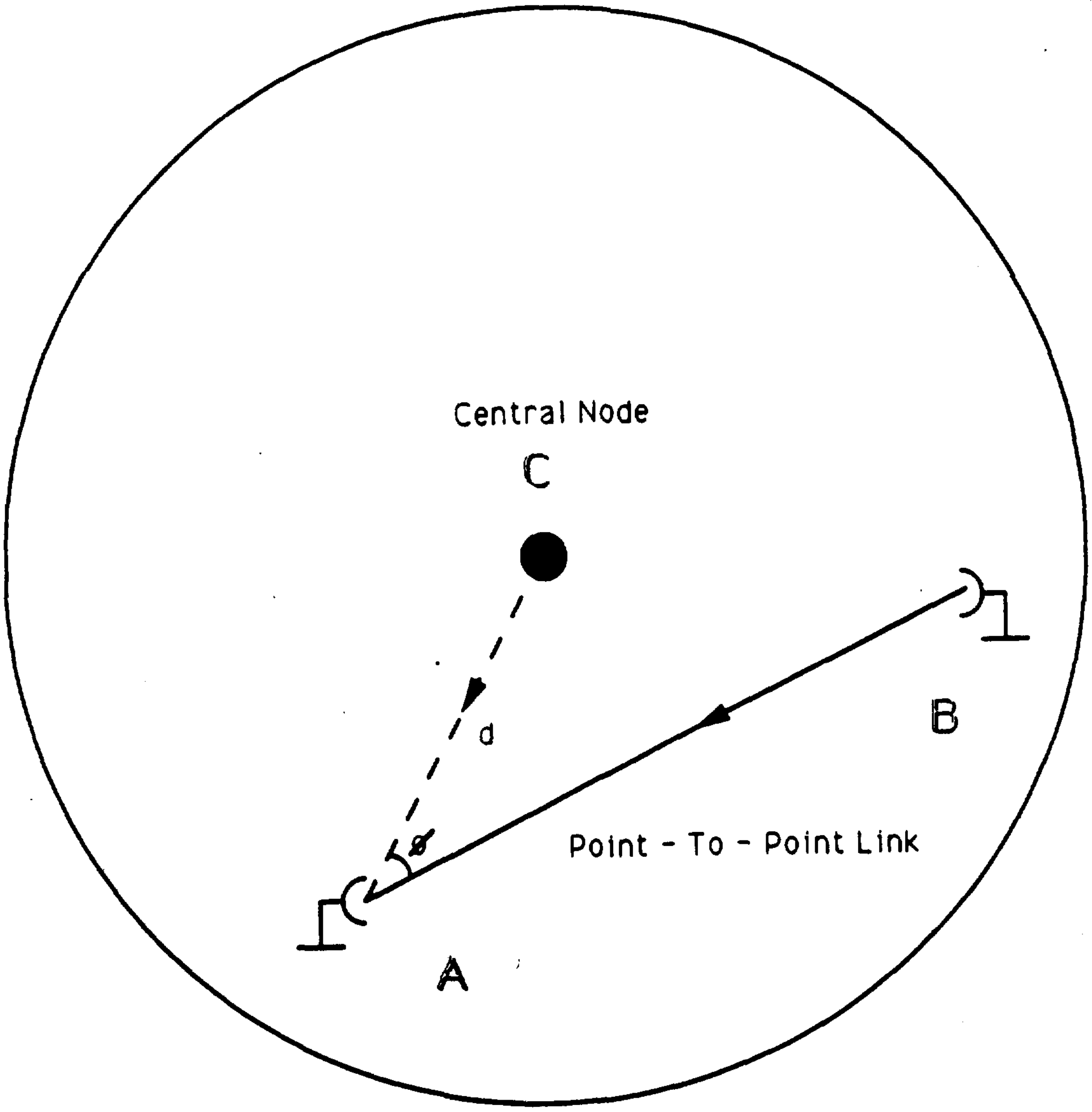

Figure II-10.1 Coexistence of the video links and point-to-point links.

Section III
Secondary Services

1. Introduction

An additional feature of the system is the future development of two-way links between the headend and subscribers. These will be used for telephone, computer data transmission, office business traffic generated from PBXs, and digital video services such as teleconferencing. A number of important requirements should be met for technical and economical viability of such a communication network. Foremost among them is the requirement that the subscriber RF and baseband equipment must be inexpensive and should be capable of receiving and transmitting signals of adequate power and bandwidth. On the RF side, transmission systems that can generate 10 to 15 dBm of power are economical to implement, and are shown here to be adequate to meet the communication requirements. For baseband signal processing systems the cost depends upon volume of production; hence choosing a system which is either an established, or an evolving, standard is essential. It is shown that such a constraint can be met.

For telephone services, FM carriers of 30 KHz bandwidth may be used initially with analog baseband. Such channels in a frequency division multiplexed mode can be fixed assigned to users, or demand assigned using a control channel, depending on the total number of circuits required. Demand assignment hardware can be inexpensively implemented using terrestrial cellular radio hardware. Since up to 15,000 telephone circuits capacity exists in the 1 GHz frequency band, the decision to use fixed or demand assigned circuits will depend upon the expected number of telephone users in the system. The demand assigned telephone circuits can be analog (or digital on the long run), using cellular radio standards.

For data services, constant or near constant envelope modulation may be used. Modulation methods, such as π/4-QPSK or GMSK, produce low out-of-band energy when transmitted through the nonlinear RF transmitting amplifier at the subscriber's premises in the subscriber-to-headend link. For instance, for digital video of teleconference quality a 200 KHz GMSK channel transmitting 270 Kbps of data will produce a bit error rate of 10^{-3} to 10^{-4} at a CNR of 13 dB. Larger size digital carriers for PBX and other business traffic can be transmitted similarly using constant or near constant envelope modulations that produce low adjacent channel interference.

The 1 GHz of bandwidth on the polarization opposite to the video band can be divided into two approximately equal parts, one for subscriber-to-headend links and the other for headend-to-subscriber links. These frequency bands may contain a mix of two-way traffic signals that will substantially depend upon the traffic requirements within the cells. The headends may be connected to the public switched telephone network.

Subscriber transmission will be typically low in power, and would not materially effect other two-way transmitting and receiver systems since there would be frequency offsets and antenna sidelobe isolation. Also use of FM will lead to substantial rejection of interference due to the strong signal capture effect. At the central node the receiving system accepts signals from all the subscriber transmitters. By adjusting the power levels at the subscriber transmitters, all the signals can be received within a dynamic range of 30 dB at the central node.

One important problem in the millimeter wave communication links is the poor frequency stability of RF oscillators as a function of temperature variations. A transmission plan with pilots, Dielectric Resonators, or internal phase-locked oscillators are used to solve this problem. Frequency errors of local oscillators may be corrected using the pilots as references. Additional stability is also provided using temperature compensation control.

2. Analog Telephony

Even though analog telephone signals are generated in 4 KHz band, transmitting them as 30 KHz FM signals is more efficient than narrowband 4 KHz AM transmission. The CNR required in AM is about 25 dB, whereas the FM channel needs only 12 dB. Even though FM has larger bandwidth, the power required per FM carrier is smaller than that of AM by about 3 dB. Since bandwidth is not a premium but power is, the advantage of FM is clear.

Assuming that 1 GHz bandwidth is allocated for the secondary services, it can be used for 16,600 simultaneous telephone conversations, which is the ideal theoretical limit. If this is the only non-video service, the capacity is large enough to allocate one circuit per customer in most of the service areas. This has the elegance that it virtually parallels the method used in standard telephone systems (except for FM and duplex features). On the other hand, this is very wasteful of the channel spectrum resource.

Terrestrial cellular mobile telephony uses 30 KHz FM transmission, and the hardware used there can also be used for the present application.

Since not all of the 1 GHz bandwidth will be available for telephony, it is useful to consider alternatives. Demand assignment of the (30 KHz) circuits is one way to improve spectral efficiency. This technique is used in cellular systems and hence inexpensive consumer hardware is available.

Recently Motorola has shown that a 30 KHz channel can be used for three telephone speeches using analog modulation; this will increase the capacity to 20,000 conversations in 400 MHz of RF bandwidth within a cell.

Besides low power, an additional related constraint is that the subscriber's transmitting amplifier be operated close to saturation. This rules out substantially analog AM modulation; other problems with AM are high CNR and low tolerance to interference. An amplifier operating at saturation exhibits substantial out-of-band signal spreading for digital signals, unless they have exactly or nearly constant envelope.

Analog FM carriers with 30 KHz bandwidth are used in terrestrial cellular radio systems. Hence a low cost technically acceptable telephone signal delivery system can be developed using such hardware, which is already available at low cost. The RF portion needs obvious changes; the cellular radio equipment uses upper UHF frequencies, which need to be up and down converted to the millimeter wave frequencies. Since several hundreds of MHz bandwidth is available here, appropriate frequency upgrading and power downgrading of the cellular radio hardware is necessary for full utilization.

As stated earlier digitally modulated signals also should have, at least approximately, constant envelope. One such modulation candidate (recommended by the US Electronic Industries Association for digital cellular systems) is $\pi/4$ - QPSK. If implemented in a bandwidth of 30 KHz, data transmission at a rate of 48.6 Kbps is possible. In a channel that provides a CNR of 13 dB, bit error rates in the range of 10^{-3} to 10^{-4} can be realized before error correction. Another modulation candidate is Gaussian Minimum Shift Keying (GMSK), which is used in the emerging European digital cellular system standard Group Special Mobile (GSM). The GSM standard specifies 200 KHz bandwidth for a data rate of 270.8 Kbps. Such a signal also can provide a bit error rate of 10^{-3} to 10^{-4} when the received CNR is 13 dB.

The EIA standard channel can support three telephone channels with digitized speech in one 30 KHz carrier. The GSM carrier can support eight traffic requirements within the cells. The headends may be connected to the public switched telephone network.

One important problem in the millimeter wave communication links is the poor frequency stability of RF oscillators. Off-the-shelf oscillators exhibit typically a stability of 20 to 30 parts per million per degree centigrade of temperature. At 28 GHz this is equivalent to frequency drifts of $\pm$ 0.5 to $\pm$ 0.75 MHz. This does not pose a problem for wideband services, such as FM video carriers, assuming that they are over stabilized. However, for narrowband signal transmission, e.g., a data carrier with 200 KHz bandwidth, this level of stability is inadequate. One economical method to solve this problem is to use a set of pilot tones. The pilots can be tracked by receivers and can be used to provide frequency error signals to the local oscillators for down converting received signals and up converting signals for transmission. Similar techniques can also be used at repeaters for efficient frequency translation.

Table III-3.1

Suite 12 System Two-Way Link Analysis
City: New York

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		**Subscriber Dish Diameter: 15 inch**	
	HS Link	**SH Link**	**HS Link**	**SH Link**
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	0.0	38.0
4. Path length, miles	3.0	3.0	.9	3.9
5. Free space loss (at 28 GHz), dB	135.1	135.1	37.3	137.3
6. Receiver antenna gain, dBi	32.0	10.0	8.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	28.2	28.2	32.0	32.0
11. Rain rate for 0.01% mm/hr	52.4	52.4	52.4	52.4
12. Rain attenuation (99.9% availability), dB	15.0	15.0	18.6	18.6
13. Rain faded CNR[1)], dB	13.0	13.0	13.2	13.2

[1)] Includes intermodulation noise at a C/IM of 27 dB

Table III-3.2

Suite 12 System Two-Way Link Analysis

City: Chicago

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		**Subscriber Dish Diameter: 15 inch**	
	HS Link	**SH Link**	**HS Link**	**SH Link**
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	3.0	3.0	3.9	3.9
5. Free space loss (at 28 GHz), dB	135.1	135.1	137.3	137.3
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10.Carrier-to-Noise Ratio (CNR), dB	28.2	28.2	32.0	32.0
11.Rain rate for 0.01% mm/hr	52.0	52.0	52.0	52.0
12.Rain attenuation (99.9% availability), dB	14.9	14.9	18.4	18.4
13.Rain faded CNR[1)], dB	3.1	13.1	13.4	13.4

[1)] Includes intermodulation noise at a C/IM of 27 dB

Table III-3.3

Suite 12 System Two-Way Link Analysis

City: San Francisco

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	4.5	4.5	6.0	6.0
5. Free space loss (at 28 GHz), dB	138.5	138.5	138.5	138.5
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10. Carrier-to-Noise Ratio (CNR), dB	24.8	24.8	28.2	28.2
11. Rain rate for 0.01% mm/hr	30.0	30.0	30.0	30.0
12. Rain attenuation (99.9% availability), dB	11.6	11.6	14.3	14.3
13. Rain faded CNR[1)], dB	13.0	13.0	13.7	13.7

1) Includes intermodulation noise at a C/IM of 27 dB

Table III-3.4

Suite 12 System Two-Way Link Analysis

City: Boston

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		Subscriber Dish Diameter: 15 inch	
	HS Link	SH Link	HS Link	SH Link
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	3.1	3.1	4.1	4.1
5. Free space loss (at 28 GHz), dB	135.3	135.3	137.8	137.8
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10.Carrier-to-Noise Ratio (CNR), dB	27.8	27.8	31.5	31.5
11.Rain rate for 0.01% mm/hr	49.0	49.0	49.0	49.0
12.Rain attenuation (99.9% availability), dB	14.4	14.4	18.0	18.0
13.Rain faded CNR[1)], dB	13.2	13.2	13.3	13.3

[1)] Includes intermodulation noise at a C/IM of 27 dB

Table III-3.5

Suite 12 System Two-Way Link Analysis

City: Los Angeles

HS link: Headend-to-subscriber link
SH link: Subscriber-to-headend link

	Subscriber Dish Diameter: 7.5 inch		**Subscriber Dish Diameter: 15 inch**	
	HS Link	**SH Link**	**HS Link**	**SH Link**
1. Transmitting RF amplifier power per channel, dBW	-2.0	-2.0	-2.0	-2.0
2. Transmitting antenna feed loss, dB	1.0	1.0	1.0	1.0
3. Transmitting antenna gain, dBi	10.0	32.0	10.0	38.0
4. Path length, miles	4.5	4.5	6.0	6.0
5. Free space loss (at 28 GHz), dB	138.5	138.5	138.5	138.5
6. Receiver antenna gain, dBi	32.0	10.0	38.0	10.0
7. Boltzmann's constant, dBW/K/Hz	-228.6	-228.6	-228.6	-228.6
8. Bandwidth (30 KHz), dB-Hz	44.8	44.8	44.8	44.8
9. Receiver noise temperature, dBK	29.5	29.5	29.5	29.5
10.Carrier-to-Noise Ratio (CNR), dB	24.8	24.8	28.2	28.2
11.Rain rate for 0.01% mm/hr	30.0	30.0	30.0	30.0
12.Rain attenuation (99.9% availability), dB	11.6	11.6	14.3	14.3
13.Rain faded CNR[1)], dB	13.0	13.0	13.7	13.7

[1)] Includes intermodulation noise at a C/IM of 27 dB

4. Digital Transmission Based Services

Switching and concentration equipment at the headend will be digitally based and hence there is an advantage to transmitting digitized speech over the links between the subscriber and the headend. Economical methods of generating digitized (and compressed) speech will be available in the future when digital TELCO local loops and digital cellular systems become popular. Using compressed speech three sources can be time division multiplexed to generate 48 Kbps (this is the emerging North American digital cellular standard). The 48 Kbps bit stream can be transmitted on a QPSK link that occupies 30 KHz bandwidth. The link requires 12 dB of CNR.

Other digital based services may require data rates varying from 19.2 Kbps to 45 Mbps, with 1.54 Mbps (T1 rate) likely to be the most popular. Such links can use QPSK or GMSK modulation, described below. Recently Motorola has shown that a 30 KHz channel can be used for three telephone speeches using analog modulation; this will increase the capacity to 20,000 conversations in 400 MHz of RF bandwidth within a cell.

Section IV
Conclusions

Because of the considerations described in this report, it is recommended that the video system be of the following type:

- Frequency modulated video channels
- 100 Watt TWTA at the transmitter, operated at 7 dB output backoff
- Transmitter antenna gain of 10 dB
- Receiver dish diameters 15 inch and/or 7.5 inch
- RF bandwidth allocated for video to be minimum 1 GHz
- Capacity of the system is 49 FM channels which are 20MHz wide
- Maximum cell diameter for
- 49 carriers, 15 inch receiver dish: 7.8 miles (NY), 12.4 miles (LA)
- 49 carriers, 7.5 inch receiver dish: 6 miles (NY), 9 miles (LA)
- Clear weather video SNR = 55 dB (minimum among all of the above)
- Faded SNR = 42 dB
- Rain availability is 99.9% in an average year
- Unavailability or reduced picture quality in fringe areas is 8.76 homes/year

Note that the unavailability of the Suite 12 system is better than that required for satellite transmissions. Satellite unavailability is the limiting factor for Suite 12 and cable distribution systems.

Minor modifications to DBS satellite (indoor unit) receiver with an IF that is 1 GHz in bandwidth (e.g. 950 to 2050 MHz) can be used for this purpose. Since many receivers are already equipped with 18 MHz filtering options, no new components need be developed. If video scrambling and pay-per-view options are required, several vendors already provide these options. The FM receiver units also come with automatic frequency control (AFC), the pull-in range of which is adequate to compensate for RF local oscillator frequency instabilities. The outdoor unit of the consumer receiver can be assembled with off-the-shelf equipment. An inexpensive version is under development at Sarnoff.

The FM transmission headend, consisting of video sources, FM modulators and RF amplifiers (100 W TWTA) can be assembled with off-the-shelf equipment provided by several manufacturers.

Rain depolarization, fade margins, and multipath are not a problem for short range millimeter wave propagation and reception by antennas that have narrow beamwidths. The proposed system would come under this category. The quality of the video will be excellent under clear weather condition (SNR in excess of 55 dB), and good even under rain faded condition (SNR of 42 dB).

Two-way communication links between the headend and subscribers have been economically established and demonstrated using low power transmitters, e.g., 5 to 10 mW transmitter power at the antenna input for a channel with 200 KHz bandwidth. These links can be used for analog or digital telephones, computer data and digital video services. By using hardware from emerging or established standards, e.g., analog and digital cellular radio systems, it is possible to develop economically the communication network in a phased manner. By relying on these standards the necessity to develop custom hardware is substantially reduced at all parts of the network, except RF transmission subsystems. Principles of millimeter wave transmission, in the context of the Suite 12 system are verified in this report and have been experimentally demonstrated at both Sarnoff and Suite 12. The inexpensive video hardware designed for the production quantities portion of this program continues in progress. The development of inexpensive two-way hardware is part of phase 3 of this program.

APPENDICES

A-1. Rain Attenuation Prediction Models

To determine rain fade margin we consider two prediction models. The first is the Crane model (IEEE Trans. Comm., Sept.,1980). Let

R	=	Rain rate in mm/hr for a given availability requirement
a	=	$3.8 - 0.6 \ln R$
b	=	$2.3\, R^{-0.17}$
c	=	$0.026 - 0.03 \ln R$
u	=	$\{\ln[b \exp(ac)]\}/a$
D_0	=	22.5 Km
α, β	=	constants that depend on frequency
A	=	Attenuation in dB for a path of length D, Km

Then

$$A = (\alpha R^{\beta})[\exp(u\beta D)-1]/(u\beta) \qquad \text{if } D < a$$

$$= (\alpha R^{\beta})[\{(\exp[u\beta a]-1)/(u\beta)\}$$

$$- \{b^{\beta}(\exp[c\beta a])/(c\beta)\}$$

$$+ \{b^{\beta}(\exp[c\beta D])/(c\beta)\}] \qquad \text{if } a \leq D \leq D_0$$

The condition of $D > D_0 = 22.5$ Km is of no interest here. At 28 GHz, the values of α and β are

$$\alpha = 0.1472$$

$$\beta = 1.081$$

The continental US is divided into rain regions, and for each region values of rain rate R are specified for several unavailability values; see Figure A-4.1 and Table A-1.1.

Table A-1.2 shows the attenuation values for 99.9%, 99.95%, 99.98%, and 99.99% availabilities in different rain regions, for D = 2 to 8 miles.

The second rain attenuation prediction model is the CCIR 1982 model (Report 338-4, paragraph 5.2). Rain regions similar to the Crane regions are developed by the CCIR. However, it is more accurate to use the rain rate contours (0.01% of the time) shown in Figure A-1.2.

Given the rain rate R corresponding to 0.01% of the time, the attenuation at this unavailability level is

$$A(0.01\%) = (\alpha R^{\beta})\, Dr$$

where

$$\begin{aligned} \alpha &= 0.1618, \text{ at } f = 28 \text{ GHz} \\ \beta &= 1.037, \text{ at } f = 28 \text{ GHz} \\ D &= \text{path distance in Km} \\ r &= 90/(90 + 4D) \end{aligned}$$

At other unavailability p (percent) values, the attenuation is given by

$$A(p \text{ percent}) = [A(0.01\%)]\,(p/0.01)^{-0.41}$$

where

$$0.01\% \leq p \leq 0.1\%$$

Table A-1.3 shows the attenuation values for several values of p, 0.01% rain rate R, and distances D.

In this study we selected New York and Los Angeles as cities with high population density and where wireless cable TV distribution has significant opportunity for deployment. For rain availability, a service level of 99.9% in an average year is chosen. This is somewhat better than typical DBS (WARC '77) specifications of 99% availability in the worst month of an average year. If the following relation

$$p = 0.29(p_w)^{1.15}$$

is used to relate the average year unavailability time percentage p, and the unavailability p_w in the worst month of an average year, then p = 0.1% corresponds to $p_w = 0.396\%$, i.e., $1\text{-}p_w$ equals 99.6%.

A comparison of the Crane and the CCIR (1982) methods can be made at New York and Los Angeles for 99.9% average year availabilities. Let the path radius, D, be 4 miles at New York and 6 miles at Los Angeles. Then the attenuation values can be computed to be

New York, 4 miles:	Crane Model attenuation = 20.36 dB
	CCIR Model attenuation = 19.03 dB
Los Angeles, 6 miles:	Crane Model attenuation = 13.02 dB
	CCIR Model attenuation = 14.41 dB

It is then seen that the models are in reasonable agreement, at least at these two cities and for the assumed availability level. (In making this comparison, the 0.01% rain rates at New York and Los Angeles are assumed to be 52.4 and 30 mm/hr respectively. At Sarnoff a complete data base of the rain rates obtained from Fig. A-1.2 exists. The New York rain rate, obtained by numerical interpolation is 52.38 mm/hr.) Such agreement cannot be expected at all cities, since Crane's model has wide regions within which the predicted attenuations would be constant, but the CCIR model has finer rain rate variations. In this study we will use the CCIR model, which has a much simpler distance-dependent factor [90D/(90 + 4D)], than the Crane model. Note that the faded rainfall attenuation factor for the radius of the cell need not be changed for application to the diameter of the cell since the transmitter radiates equally in all directions. For the purposes of this study we assumed a worst-case situation in which the maximum rainfall intensity was the same throughout the cell. In reality, rainfall over a large area is not homogeneous and the maximum is usually limited to a diameter of less than one mile. Additionally, the Bossard analysis allows for an increase in transmitter power when the rainfall is heavy. This study does not take into account this factor, which would increase the availability. The results of this study are considered to be very conservative.

TABLE A-1.1
POINT RAIN RATE DISTRIBUTION VALUES

Percent of Year	Rain Climate Region									
	A	B	C	D_1	D_2	D_3	E	F	G	H
0.001	28	54	80	90	102	127	164	66	129	251
0.002	24	40	62	72	86	107	144	51	109	220
0.005	19	26	41	50	64	81	117	34	85	178
0.01	15	19	28	37	49	63	98	23	67	147
0.02	12	14	18	27	35	48	77	14	51	115
0.05	8.0	9.5	11	16	22	31	52	8.0	33	77
0.1	5.5	6.8	7.2	11	15	22	35	5.5	22	51
0.2	4.0	4.8	4.8	7.5	9.5	14	21	3.2	14	31
0.5	2.5	2.7	2.8	4.0	5.2	7.0	8.5	1.2	7.0	13
1.0	1.7	1.8	1.9	2.2	3.0	4.0	4.0	0.8	3.7	6.4
2.0	1.1	1.2	1.2	1.3	1.8	2.5	2.0	0.4	1.6	2.8
Number of Station Years of Data	0	25	44	15	99	18	12	20	2	11